described above. If formula (1) is not satisfied, then by experiment it has been found that the resulting copper alloy does not provide the degree of machinability and other properties shown in Tables 18-32.

[0077] We describe the contribution to the relationship of constraint formula (1) by elements other than copper, silicon and zinc in formula (2) as follows:

(2) $a_o Z_o = a_1 Z_1 + a_2 Z_2 + a_3 Z_3 + \ldots..$

where a_1, a_2, a_3, etc., are experimentally determined coefficients, and Z_1, Z_2, Z_3 , etc., are percents, by weight, of elements in the composition other than copper, silicon and zinc.

[0078] Specifically, it has been determined that in order to practice the copper alloys of the present invention, the "**a**" coefficients are as follows: for lead, bisthmuth, tellurium, selenium, antimony, arsenic and titanium, the a coefficient is zero; for aluminum, the **a** coefficient is –2; for phosphorus, the **a** coefficient is –3; for chromium, the **a** coefficient is +2; and for manganese and nickel, the **a** coefficient is +2.5. It will be appreciated by one skilled in the art, that formula (1) does not directly constrain the amounts of lead, bismuth, tellurium, selenium, antimony, arsenic and titanium in the copper alloys of the present invention because the **a** coefficient is zero for these elements; however, these elements are indirectly constrained by the fact that the percent, by weight, of copper, silicon, and those elements in the copper alloy and having non-zero a coefficients must satisfy constraint formula (1).

[0079] To be even more specific, for the first and second invention alloys, constraint formula (1) can be written as:

(3) $60 \leq X - 3Y \leq 70$,

where X is the percent, by weight, of copper and Y is the percent, by weight, of silicon in the alloy.

[0080] For the third, fourth, eighth and nineth invention alloys, constraint formula (1) can be written as:

(4) $60 \leq X - 3Y + aZ + bW \leq 70$,

where X is the percent, by weight, of copper; Y is the percent, by weight, of silicon; Z is the percent, by weight of aluminum; W is the percent, by weight, of phosphorus in the alloy; a is –2; and b is –3.

[0081] For the fifth, sixth and twelfth invention alloys, constraint formula (1) can be written as:

(5) $60 \leq X - 3Y + aZ \leq 70$,

where X is the percent, by weight, of copper; Y is the percent, by weight, of silicon; Z is the percent, by weight of phosphorus in the alloy; and a is –3.

[0082] For the tenth and eleventh invention alloys, constraint formula (1) can be written as:

(6) $60 \leq X - 3Y + aZ + bW + cV \leq 70$,

where X is the percent, by weight, of copper; Y is the percent, by weight, of silicon; Z is the percent, by weight of aluminum; W is the percent, by weight, of phosphorus; V is the percent, by weight, of chromium in the alloy; a is –2; b is –3; and c is +2.

[0083] For the seventh invention alloy, constraint formula (1) can be written as:

(7) $60 \leq X - 3Y + aZ + bW + cV + dU \leq 70$,

where X is the percent, by weight, of copper; Y is the percent, by weight, of silicon; Z is the percent, by weight of aluminum; W is the percent, by weight, of phosphorus; V is the percent, by weight, of manganese; U is the percent, by weight, of nickel; a is –2; b is –3; c is +2.5; and d is +2.5. It has also been determined for the seventh invention alloy that a

secondary alloy composition constraint is necessary to practice the invention. This secondary alloy composition constraint formula is a ratio involving silicon, manganese and nickel describing the constraining composition as follows:

(8) $$0.7 \leq Y/(V + U) \leq 6,$$

where Y, V and U are the percents, by weight, of silicon, manganese, and nickel respectively.

[0084] To summarize, all of the first through the twelfth invention alloys of the present invention must satisfy the alloy composition constraint of Formula 1, and all of the illustrative examples in Tables 1-8 and 10-16 comply with this composition constraint. Only the seventh invention alloy is further constrained by the secondary alloy composition constraint of Formula 8. Other copper alloys that contain include the same elements as the copper alloys of the present invention, but which do not have a composition satisfying the requirements of Formula 1, and when appropriate Formula 8 as well, will not have the characteristics of the copper alloys disclosed in Tables 1-8 and 10-16.

METAL CONSTRUCTION

[0085] Another important feature of the copper alloys of the present invention is the metal construction, being the matrix of the metal, formed by the integration of multiple phase states of the component metals, which produces a composite phase for the copper alloy. Specifically, as one skilled in the art will appreciate, a given metal alloy may have different characteristics depending upon the environment in which it was produced. For example, applying heat to temper steel is well known. The fact that a given metal alloy may behave differently depending upon the conditions in which it was forged is due to the integration and conversion of components of the metal to different phase states. As is illustrated in Tables 1-8 and 10-16, the copper alloys of the present